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Method and device for Fault Detection in Transformers

Technical Field of the Invention

This invention relates to a method and a device for improved protection of power transformers, autotransformers or power lines from the effects of internal or external faults by using an advanced differential protection system.

Background of the invention

Faults in power transformers may lead to widespread consequences, both in the form of power failure for a large group of customers and in the form of that the faulty transformer has to be exchanced or at least repaired. Both consequences are troublesome and costly for the supplier of the electrical power. The consequences of unwanted disconnections of healthy equipment, such as power transformers, is also very costly. In the worst case, the unwanted disconnections can result in wider black-outs.

Protection devices such as differential relays normally safeguard power transformers. Differential relays typically have a minimum operating current level set to 30% of the protected power transformer current rating. The set value should be that high in order to prevent unwanted operation of the differentia relay due to the On Load Tap Changer (OLTC) that typically is used in modern power transformers. When OLTC moves from one position to another, amplitude mismatch between power transformer winding currents will outcome causing a false differen-

15% of rated voltage so the contribution of around 15% to differential current may occur.

The set value should also be high enough in order to prevent unwanted operation of the differential relay due to Protection CT (current transformer) errors, or unequalities.

Known transformer differential relays are usually not sensitive enough for low-level internal faults, which may happen for example within a power transformer tank. Power transformer winding turn-to-turn faults belong to such type of internal faults. In the same time, according to available fault statistic, turn-to-turn faults are one of the most common internal faults inside a power transformer.

Traditional power transformer differential relays utilize individual phase currents from different windings of the transformer in order to form the phase-vise differential currents. In modern numerical differential relayes these differential currents are usually formed by using mathematical equations, which are dependent on the vector group of the power transformer.

The most common weaknesses of a traditional power transformer differential protection are long operation delays in case of heavy internal faults followed by main CT saturation due to 2nd harmonic blocking feature, and unwanted operations for externa faults. They also have bad sensitivity for low level internal faults, i.e. winding turn-to-turn faults, which are thus allowed to develop into more severe faults, involving the powe transformer iron core.

Long delays for heavy internal faults, they can be in the order of several tens of milliseconds, are a consequence of the harmonic distortion of the fault currents as they are seen by the differential relay. The harmonic distortion is due to initial heavy saturation of the current transformers under fault condition. Harmonic restrain criterion prevents immediate operation of the differential protection.

Further, power transformer differential protections show a tendency to unwanted operations for faults external to the protected zone with the power transformer, particularly for external earth faults.

Within this area of technology several inventions try to deal with these kinds of problems and some patents have been granted.

As an example **US 5514978** is a patent that includes measureing of negative sequence impedance by using voltage measurements! The document describe an invention that determins the existence of a turn fault that comprises estimating a current differential by dividing the negative sequence voltage phasor by a characteristic negative sequence impedance and subtracting the result from the negative sequence current phasor, and comparing the estimated current differential with athreshold current differential.

In the present invention measurements of the voltage is not used at all. The present invention is instead based on comparison of negative sequence currents from the diffrent sides of the protected power transformer.

The patent **US6507184** concerns a method and apparatus for differential current measurement in a three-phase power system. This invention is arranged to measure the differential current between a first and a second terminal and to obtain, for each phase, a measure of these currents. This patent does not involve a negative sequence differential protection at all.

The invention according to the patent **US6518767** concerns protection of power transmission lines and includes tripping of the circuit breaker. Similar circuitry is also used for negative sequence current quantities, with the negative secuence preselected values being set substantially lower to produce a more sensitive response to possible faults in the line.

The present invention concerns mainly the technical area of power transformer protection, but can as well be extended as power line protection or a combination of them, while the above patent concerns protection of a power transmission line only. The power transformer according to the present invention introduces phase shift and voltage level difference between power transformer sides. Therefore the negative sequence currents from different power transformer sides have to be first related to each other. After that the negative sequence current differential principle or method is used and a direction comparison is made to protect power transformers against short-circuit and ground faults. Above this the presen invention as well protect the power transformer against turn-to-turn faults, which are series faults and not a shunt fault as in the patent application US6518767. This turn-to-turn faul protection capability is an important advantage of the present invention. This turn-to-turn fault is the most common, but in

the same time the most difficult, fault to detect within a power transformer/autotransformer.

The patent application **WO02/33426** concerns a line differential protection system for a power transmission line. All three phase current values are obtained from both the local end and the remote end of a power transmission line. Comparison elements are aranged to compare the ratio and angel values against preselected values, which establish a restrain region in the current ratio plane. Current values, which result in a ratio outside of the region, result in a tripping of the circuit breaker. Similar circutry is used for negative sequence current quantities, with the negative sequence preselected values being set substantially lower to produce a more sensitive response to possible faults in the line.

This invention also concerns a differential protection system for a power transmission line. The system is not usable for a power transformer protection system.

Summary of the invention

The object of the present invention is to solve above indicated problems and present a method and a device for efficient detection of a fault in a power transformer. Another object of the present invention is to detect if the fault is internal or external. A further object of the present invention is to detect if the fault is symetrical or unsymetrical. Another object of the present invention is to present a method and a device that is able to detect turn-to-turn faults very fast an with high sensitivity.

A method for fault detecting in a power transformer according to the invention is achieved by,

- measuring of individual phase currents on all transformer sides,
- calculating individual phase currents fundamental frequency phasors,
- calculating contribution of the individual side negative sequence currents to the total negative sequence transformer differential current,
- comparing of their individual side negative sequence currents and, by that
- determining wether the source of the negative sequence currents, the fault position, is within a protected zone or outside a protected zone, delimited with current transformers, and thereby tripping a circuit breaker for disconnecting the faulty power transformer/autotransformer or interconnected power lines.

A device, for detecting a fault in a transformer, according to the present invention is characterized by that the device is including a fault discriminator, that is arranged to determine when a fault occurs and to determine if the fault is internal or external.

Brief Description of Drawings

For better understanding of the present invention, reference will be made to the below drawings/figures.

Figure 1 illustrates the connection of current transformers, defining the positive direction of currents.

Figure 2 illustrates trajectories of the phasors representing the contributions to the total negative sequence differential current from the power transformer primary (HV) and secondary (LV) sides, for an external earth fault on the HV side.

Figure 3 illustrates the trajectory of a phasor with a magnitude equal to the magnitude of the contribution from the primary (HV) side of the power transformer, and a phase angle equal to the phase angle between the two contributions.

Figure 4 illustrates the trajectory of a phasor with a magnitude equal to the magnitude of the contribution to the total negative sequence differential current from the HV side (Y), and a phase angle equal to the phase shift between both contributions.

Figure 5 illustrates an external single-phase earth fault (L1-E) on the HV (Y) side of an Yd1 power transformer at t = 42 ms, and an internal inter-turn fault (10 %) in phase L2 on the HV side Y winding at t = 62 ms.

Figure 6 illustrates currents for an L2-L3-E internal fault on the secondary winding (d1) of an Yd1d5 power transformer.

Figure 7 illustrates Directional comparison primary - secondary, shown for the first 57 ms after the fault occured.

Figure 8 illustrates Directional comparison primary - tertiary, shown for the first 57 ms after the fault.

Figure 9 illustrates binary output signals of the differential protection.

Figure 10 illustrates trajectories of the contributions to the total negative sequence differential current for the first 25 ms after two simultaneous external faults (L1-E on the secondary, L1-E on the tertiary side).

Figure 11 illustrates when false negative sequence differentia currents sets in.

Figure 12 illustrates Directional comparison made on the contributions to the total negative sequence differential current from the primary, and secondary sides.

Figure 13 illustrates Directional comparison made on the contributions to the total negative sequence differential current from the primary, and tertiary sides

Figure 14 illustrates relative angles between contributions to the negative sequence differential current, and the output signal of the internal / external fault discriminator for two simultaneous external faults.

Figure 15 illustrates magnitudes of the negative sequence differential current, and its components, for an internal three-phase fault on an Yd1d5 transformer.

Figure 16 illustrates directional tests for an internal three-phase fault on an Yd1d5 transformer, first 25 ms.

Figure 17 illustrates output signals for an internal wholly symmetrical three-phase fault.

Detailed Description of Preferred Embodiments

In figure 1 is illustrated an internal/external fault discriminator for protection of power transformers. The fault discriminator is made on pairs of components of the total negative sequence differential current. This discriminator may be implemented as a complement to the normal power transformer differential protection.

The internal / external fault discriminator determines the position of the source of the negative sequence fault currents with respect to the protected zone. If the source of the

negative sequence fault currents is found to be outside the protection zone, then the fault is external.

If the source is found to be inside the zone, the fault is internal. The position of the negative sequence current source is determined as follows. At an internal fault, a degree of negative sequence differential current appears, and its two components (for a two-winding power transformer) are of the same direction, i.e. out of the protection zone.

At an external fault, the total negative sequence differential current remains zero or is very small, until CT saturation sets in, while its two components are equal in magnitude, until CT saturation sets in, and of the opposite direction, i.e. one in, and the other out of the protection zone.

The internal / external fault discriminator can only be active when the protected power transformer is energized and loaded as well.

Both detection of faults, and a secure discrimination between internal and external faults can be achieved based on an analysis of the negative sequence differential current, or better, based on an analysis of its two (or three at three-winding transformers) separate components, or separate parts. With a reliable fault discrimination algorithm, the power transformer differential protection

- operates very fast for heavy internal faults,
- is stable against external faults,
- operates for minor internal faults, as inter-turn.

Existence of a relatively high negative sequence current is in itself a proof of a disturbance on the power system, possibly a fault. The source of negative sequence current is at fault. Thus, if the source of the negative sequence current is found to be outside the protected zone, which includes the power transformer, then the fault must be external, and nothing shall be done in a short term. On the other hand, if the source of the negative sequence current is found to be inside the protection zone, then the fault is internal, that is, a fault on the protected power transformer can be suspected, and the transformer shall be disconnected from the power system immediately. The information on whether the fault is internal or external is obtained within about one half of the fundamental power system cycle after the fault has occured.

The principle of negative-sequence-current-based directional criterion gives a fast and reliable discrimination between external and internal faults. This is quite logical in the case of unsymmetrical faults, where the negative sequence currents are expected to exist. But the principle is just as efficient at wholly symmetrical three-phase faults. The reason is that when a symmetrical fault occurs, the negative sequence system exists for a while, i.e. until the dc components in the fault currents vanish. This interval of time is long enough for the directional criterion to positively distinguish between an internal and an external fault.

In the following the principle of the discriminator is discribed. In order to define what is meant by the "same direction", and by the "opposite direction", an explanation of this is as follows.

For an external fault, with the negative sequence source at the point of fault, it is clear that the negative sequence currents enter the healthy power transformer on one side, and leave it on the other side, properly transformed. According to Figure 1, the negative sequence currents on the respective power transformer sides have opposite directions, or better, the differential protection sees these currents with a relative phase shift of 180 degrees.

For an internal fault (with the negative sequence source at the point of fault) it is clear that the negative sequence currents leave the faulty power transformer on both sides. According to Figure 1, the currents on the respective power transformer sides have the same direction, the differential protection sees these currents with a relative phase shift of 0 degrees. In reality, there may be some phase shift between these currents due to different negative sequence impedance angles of the circuits on the respective power transformer sides, while the magnitudes of the negative sequence currents depend on the magnitudes of the negative sequence impedances of circuits on the respective sides.

The same coefficient matrices can be used for the calculation of the negative sequence differential currents as they are used for the calculation of the "common" power transaformer/autotransformer differential current. The only difference is that the individual winding negative sequence currents must be fed into the equation instead of the individual winding phase currents. The coefficient matrices allow for power transformer ratio and vector group connection. Because the negative sequence differential currents are symmetrical, only one differential current needs to be calculated, for example the

negative sequence differential current in phase L1, i.e. Idns_L1. The negative sequence differential current must be calculated on a regular base and be available at any time.

$$\begin{bmatrix} Idns\_L1 \\ Idns\_L2 \\ Idns\_L3 \end{bmatrix} = \underbrace{\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} * \begin{bmatrix} Ins\_A \\ Ins\_B \\ Ins\_C \end{bmatrix}}_{\text{Contribution to total negative seq. current from the HV side (Y)}} + \underbrace{\begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} * \begin{bmatrix} Ins\_a \\ Ins\_b \\ Ins\_c \end{bmatrix}}_{\text{Contribution to total negative seq. current from the LV side (d)}}$$

The total negative sequence differential current Idns_L1 is low (theoretically zero) in case of an external fault, and high in case of an internal fault. More important, however, than the total negative sequence differential current itself, are in this context its two (three for a three-winding power transformer) components, the one from the primary HV side, and one from the secondary LV side. These two components are compared as to their direction by the fault discriminator, in order to decide whether the fault is internal or external.

The two components of the total negative sequence differential current are phasors. Each of them has a magnitude and a phase in the complex plane. To be able to make a trustworthy directional comparison on these two phasors, each of their magnitudes must exceed a certain minimum value. Otherwise, no directional comparison is allowed. The minimum value must be above values that can be measured during normal operation of

the power system. This value is up to a couple of percent of the power transformer rated current.

If both contributions to the total negative sequence differential current exceed the minimum value, which in itself can be taken as a sign that a fault must have happened, as the negative sequence currents are a superimposed, a pure-fault quantity, then a directional comparison is made. The relative phase angle between both phasors, which represent the respective contributions, is determined. Based on the value of this relative phase angle, an internal or external fault is detected and declared.

Figure 2 illustrates the situation for an external single-phase earth fault on the earthed Y side of an Yd1 transformer. There is little or no current transformer saturation. At any point of time, the phase angle between the two phasors was 180 degrees. The sum of these two phasors, which is the total negative sequence differential current, was nearly zero at all times, which corresponds to the fact that the fault was external. Current transformers were connected as in Figure 1.

Based on the phase angle between the two phasors, an internal or an external fault is declared. Figure 3 shows the complex plane again, but this time the relative phase angle between the two phasors is displayed. An internal fault is declared if the angle stays within ±60 degrees under an interval of time.

The internal / external boundary shown in Figure 3, was verified by means of more than 150 tests with simulated faults The form of the boundary mirrors the fact that the differentia protections display a tendency for unwanted trips for external

faults. One of the most important factors to be taken into account when forming the boundary is current transformer saturation phenomenon. The case documented in Figure 2 and Figure 3 is a simple one, with negligible current transformer saturation.

Combined with some additional safety measures, such as time constraints, the internal / external fault discriminator as shown in Figure 3, has proved reliable. As a consequence, the internal / external fault discriminator was given a highest authority than it had been intended. It takes normally about 1(ms after a fault to detect the fault and classify it as internal or external.

The internal / external fault discriminator only works if the protected power transformer is connected to some load, so that currents can flow on both sides of the power transformer, or a least two sides in case of a three-winding power transformer. Thus, at an initial current inrush, the algorithm declares neither internal, nor external fault. In such cases one has to rely on the usual features of the differential protection, suc as, for example, the harmonic restraint, or the waveform restraint for inrush. Likewise, an internal fault on an energized, but unloaded power transformer is not detected by the fault discriminator.

As the newly introduced fault discriminator proved to be very reliable, it has been given a great power. If, for example, a fault has been detected, i.e. start signals set, and it is found to be an internal one, then any eventual block signals produced by either the harmonic or the waveform restraints, ar ignored. This assures the response times of the protection

below 20 ms, even for heavy internal faults with severely saturated current transformers.

External faults happen ten to hundred times more often than internal ones. Many differential protection relays have a rather poor stability against external faults. If a fault has been detected, and it is found to be an external one, any trip request is cancelled. This assures high stability against external faults. There is, however, an interesting exception, which copes with minor internal faults, such as inter-turn faults, which may occur due to, and immediately after, an external fault. The idea behind this feature is as follows.

If an external fault is being signalized without interruption, while the zero sequence currents have been eliminated from the fundamental frequency differential currents (an option), and ar eventual On-Load-Tap-Changer (OLTC) movements compensated for, and then one or more start signals are set, but at the same time no harmonic restrain signals (neither the external, nor the internal fault, caused current transformers to saturate), then a minor internal fault can be suspected. This minor internal fault can be prevented from developing into a major one by immediate disconnection of the faulty power transformer, without waiting for the external fault to be cleared first.

As a special precaution, the so-called "cross-blocking" logica: scheme (an option otherwise) is automatically imposed for a while. Point A in Figure 4 corresponds to the external fault only. Point B corresponds to simultaneous external and interna: faults. The internal fault occurred 20 ms after the external one. Point C corresponds to the situation after the external fault has been cleared by some other protection in 128 ms,

while the internal fault persists. The differential protection actually operates already at point B and disconnects the power transformer, in spite of the fact that the point B is deep in the restrain area because of the dominant (heavier) external fault. The faulty power transformer is disconnected 15 ms (exclusive the output relay) after the inception of the internal fault.

Figure 4 shows trajectory of a phasor with a magnitude equal to the magnitude of the contribution to the total negative sequence differential current from the HV side (Y), and a phase angle equal to the phase shift between both contributions.

Figure 5 displays some of the currents against time for the example case, as shown in Figure 4. The external fault simulated was a single-phase earth fault (L1-E) on the Y side of an Yd1 power transformer (at t = 42 ms), while the internal fault was an inter-turn fault (10 %) in phase L2 on the HV-side Y winding (at t = 62 ms).

The instantaneous differential currents (where the zero sequence currents are never subtracted) are equal in all phases under only external earth fault condition. The instantaneous differential currents in all phases are equal to the zero sequence current, which cannot be properly transformed by an Yd1 power transformer.

Figure 5 shows an external single-phase earth fault (L1-E) on the HV (Y) side of an Yd1 power transformer at t = 42 ms, and an internal inter-turn fault (10 %) in phase L2 on the HV side Y winding at t = 62 ms. External fault was cleared at t = 128

ms. The faulty power transformer was disconnected 15 ms after the inception of the internal fault.

If, for some reason, the operate-restrain characteristic of the differential protection must be set relatively high (for example because of an uncompensated OLTC), then minor internal faults cannot be detected by electrical protections before they develop into major ones, with more severe damage to the power transformer as a consequence.

A special protection, based exclusively on the internal / external fault discriminator has been introduced, which is a completely independent part of the differential protection. This protection is called the Sensitive Negative Sequence Differential Protection (SNSDP) and has no logical connection to the "usual" differential protection algorithm. No start signal has to be issued by the latter in order to activate the SNSDP.

The SNSDP is more sensitive than the "usual" differential protection algorithm. Inter-turn faults including more than about 2 % of turns of a winding can be detected. An extra delay of 20 ms has been added as a precaution. Operate times of about 30 ms to 40 ms can be expected, which are better than the electromechanical Buchholtz relay's 50 ms to 150 ms.

The principle of the internal / external fault discriminator can be extended to power transformers with three windings. If all three windings are connected to their respective networks, then three directional comparisons can be done, but only two comparisons are necessary in order to positively determine the position of the fault with respect to the protected zone. The

directional comparisons, which are possible, are: primary - secondary, primary - tertiary, and secondary - tertiary. The rule applied by the internal / external fault discriminator in case of three-winding power transformers is,

- If all comparisons indicate an internal fault, then it is an internal fault.
- If any comparison indicates an external fault, then it is an external fault
- If one of the windings is not connected, the algorithm automatically reduces to the two-winding version. Nevertheless, the whole power transformer is protected, inclusive the non-connected winding.

An internal fault L2-L3-E on the secondary winding (d1) of a three-winding power transformer, connection group Yd1d5, has been simulated by EMTP - ATP. The currents on the primary- and secondary sides, and the instantaneous differential currents, are shown in Figure 6.

The two directional comparisons, made by the internal/external fault discriminator on the contributions to the total negative sequence differential current from the primary and secondary sides, both indicated an internal fault, this is a fault within the protection zone. Figure 7 illustrates Directional comparison primary - secondary, shown for the first 57 ms after the fault. The indication was steadily "internal fault" and figure 8 shows Directional comparison primary - tertiary, shown for the first 57 ms after the fault. The indication was steadily "internal fault".

Deviations of the relative phase angle from zero degrees in Figure 7 and Figure 8 were mainly due to current transformer

saturation. Severe current transformer saturation is the most dangerous enemy of the internal/external fault discriminator, but means have been found to minimize its negative effects.

It will be noticed in Figure 9 that the "usual" differential protection (signal named tripRestrained) was delayed due to harmonic and waveform restrain criteria. Besides, this signal was unstable (on - off - on, etc). The "usual" unrestrained differential protection limit, which had been set to 10 times transformer rated current, was not exceeded due to heavy ct saturation, and thus no help from the unrestrained differential protection was obtained. The faulty power transformer was tripped 15 ms after the fault occurred. It was tripped by the Negative Sequence Differential Protection.

The internal / external fault discriminator behaved correctly even in such complicated cases as two simultaneous external faults on two different sides of a three-winding power transformer. Figur 10 illustrates a case with two simultaneous external faults, one was a L1-E fault on the secondary side-, while the other one was a L1-E fault on the tertiary side of ar Yd1d5 power transformer. In this case, there existed two zero sequence current sources, both outside the protection zone. These sources were (5 - 1) * 30 degrees = 120 degrees apart. How the respective contributions to the total negative sequence differential current were placed in the complex plane is also shown in Figure 10.

The contributions are no more 180 degrees, or approximately 0 degrees apart. Their positions now theoretically depend on the position and the kind of the two faults, and practically also on the degree of saturation of current transformers. As long a:

there is no ct saturation, the total negative sequence current, which is a geometrical sum of all three contributions, is zero. When current transformer saturation sets in approximately 10 ms after the faults, false negative sequence differential currents begin to appear. This is shown in Figure 11.

The two directional comparisons made are shown in Figure 12, and Figure 13. Figure 12 displays directional comparison made on the contributions to the total negative sequence differential current from the primary-, and secondary sides. Observe that this comparison indicated for a short time (3 ms), that the fault was internal. Figure 13 displays directional comparison made on the contributions from the primary, and tertiary sides. Observe that this comparison ended up indicating that the fault was internal. This happened because of the current transformer saturation. Without it, an external fault would be indicated permanently also by this check.

Though the separate directional tests occasionally and temporarily gave wrong indication (i.e. internal fault), the internal / external fault discriminator produced the correct answer on its output, and that was: external fault. This is documented in Figure 14, where the relative angles, and the Boolean output of the discriminator are drawn against time. The signal "external fault" was issued 9 ms after the faults, and it was then stable all the time.

The negative-sequence-current-based directional principle yields a fast and reliable discrimination between external and internal faults. This is easy to understand in case of unsymmetrical faults, where the negative sequence system is expected to exist. But the principle is just as efficient in case of

wholly symmetrical faults. The reason is that when a (symmetrical) three-phase fault occurs, the negative sequence current source appears at the fault for a while, more exactly, until the dc components in the fault currents die out. As far as power transformers are concerned, this interval of time is long enough for the directional criterion to declare either an internal or an external fault.

Figure 15 shows magnitudes of the negative sequence differential current, and its components, for an absolutely symmetrical internal three-phase fault on the Y side of an Yd1d5 power transformer as they were calculated by the differential relay. The current samples, taken at a rate of 1 kHz, had been first filtered by Fourier filters. It took in this example about 20 ms for current transformers to reach heavy saturation. (The time to ct saturation is typically one cycle or longer). The existence of the false negative sequence currents after saturation set in was not a surprise; more interesting was that the negative sequence system appeared immediately following the inception of a symmetrical fault.

Figure 16 shows that under the first 22 ms after the fault both directional tests correctly indicated an internal fault, which was long enough to disconnect the faulty power transformer 14 ms (output relay make time not included) after the fault.

Figure 17 shows the output signals for an internal wholly symmetrical three-phase fault. An internal fault was declared 5 ms after the fault, the negative sequence the differential protection issued a trip request after 12 ms, and the power transformer was switched off the power system in 14 ms.

The negative sequence quantities are used extensively in the field of relaying protection, particularly in the protection of power lines. The existence of relatively high negative sequence currents is in itself an indication of a disturbance, as the negative sequence currents are superimposed, pure-fault quantities. The negative sequence quantities seem to be particularly suitable for different kinds of directional tests. One advantage of the negative sequence quantities, as compared to the zero sequence ones, is that they are not stopped at a power transformer of the Yd, or Dy connection. Negative sequence quantities are properly transformed to the other side of any power transformer.

The protection principle of the present invention can easily be extended and applied for the protection of multi-winding power transformers as well as for the protection of autotransformers.

A method according to the invention may also, at least partly, be performed under control of a set of computer readable instructions or code means contained in a computer program storage device for making a computer or processor perform any of the steps of the above described method.

The invention may also use a computer readable product for carrying out the method according to the invention.

While the present invention has been described in terms of the preferred embodiments, the invention is not limited thereto, but can be embodied in various ways without departing from the principle of the invention as defined in the appended claims.

Claims

1. Method for fault detection in a power transformer/-autotransformer and interconnected power lines, which are within the same differential protection zone and more importantly for detecting turn-to-turn faults in power transformer/autotransformer windings as well,
characterized by,
- measuring of individual phase currents on all transformer sides,
- calculating individual phase currents fundamental frequency phasors,
- calculating contribution of the individual side negative sequence currents to the total negative sequence transformer differential current,
- comparing of their individual side negative sequence currents and, by that
- determining wether the source of the negative sequence currents, the fault position, is within a protected zone or outside a protected zone, delimited with current transformers, and thereby tripping a circuit breaker for disconnecting the faulty power transformer/autotransformer or interconnected power lines.

2. Device for detecting a fault in a power transformer, auto-transformer or interconnected power lines,
characterized by that,
the device is including a fault discriminator, that is arranged to determine when a fault occurs.

3. Device according to claim 2,
characterized by that,
the device is including a fault discriminator, that is arranged to determine if the fault is internal or external.

4. A computer program comprising computer program code means for carrying out the steps of a method according to claim 1.

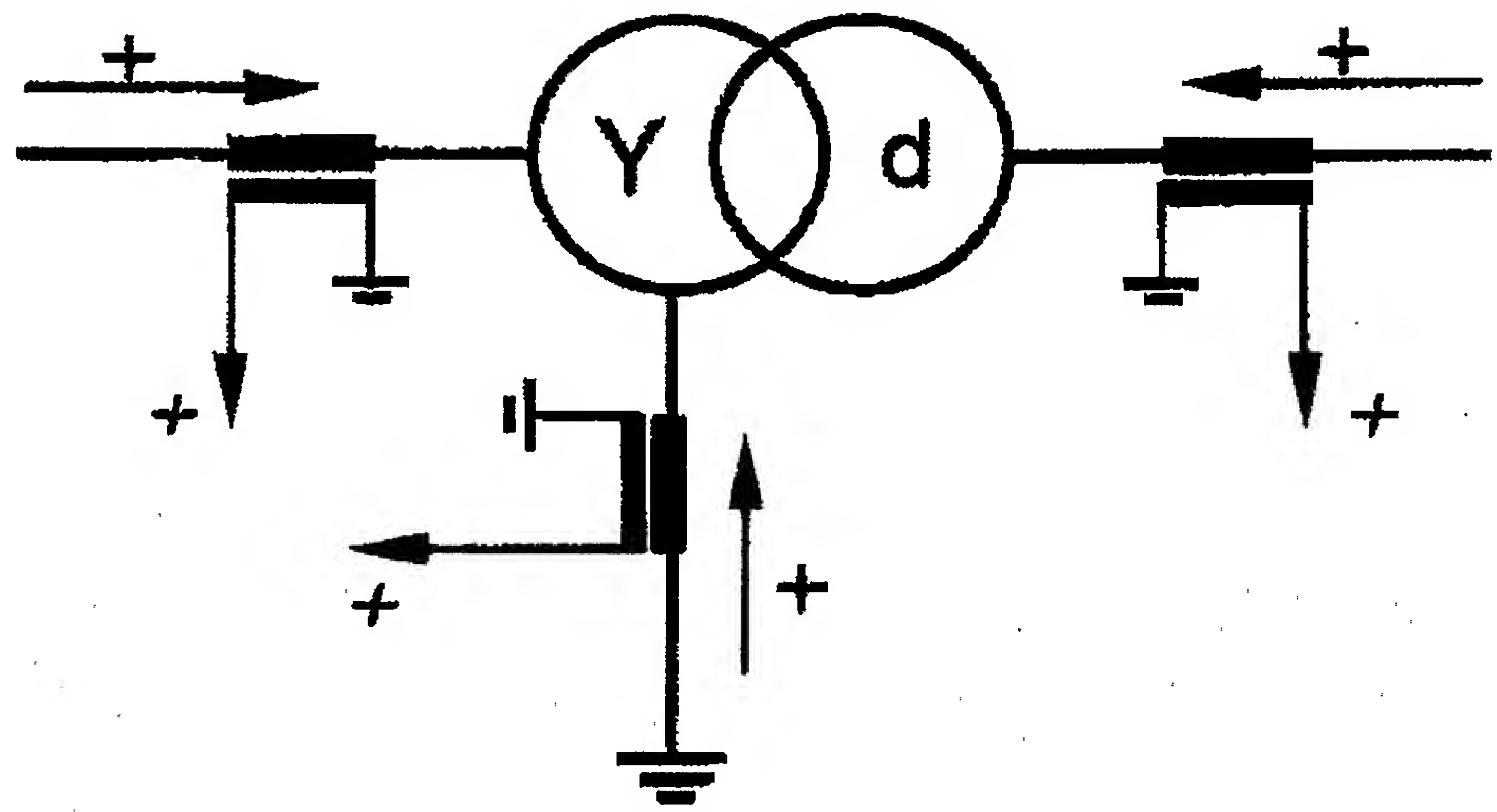
5. A computer readable medium comprising at least part of a computer program according to claim 4.

6. A computer program, according to claim 4, that is, at least partially, provided through a network, such as e.g. internet.

Abstract

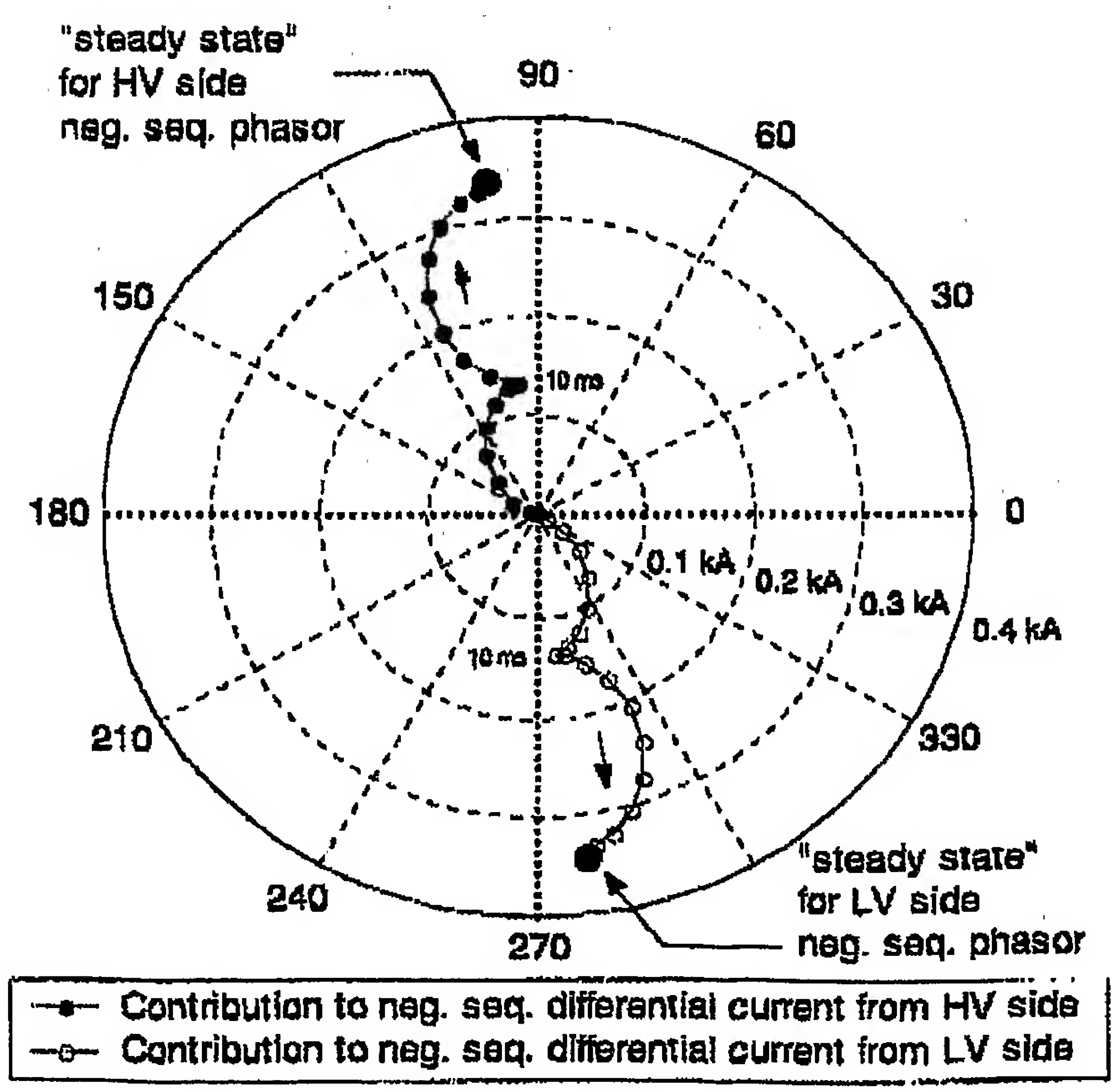
The invention refers to a method for fault detection in a power transformer/autotransformer and interconnected power lines, which are within the same differential protection zone and more importantly for detecting turn-to-turn faults in power transformer/autotransformer windings as well. The method according to the invention is achieved by the following method steps;

- measuring of individual phase currents on all transformer sides,
- calculating individual phase currents fundamental frequency phasors,
- calculating contribution of the individual side negative sequence currents to the total negative sequence transformer differential current,
- comparing of their individual side negative sequence currents and, by that
- determining wether the source of the negative sequence currents, the fault position, is within a protected zone or outside a protected zone, delimited with current transformers, and thereby tripping a circuit breaker for disconnecting the faulty power transformer/autotransformer or interconnected power lines.



+ : *positive direction of a current*

Figure 1



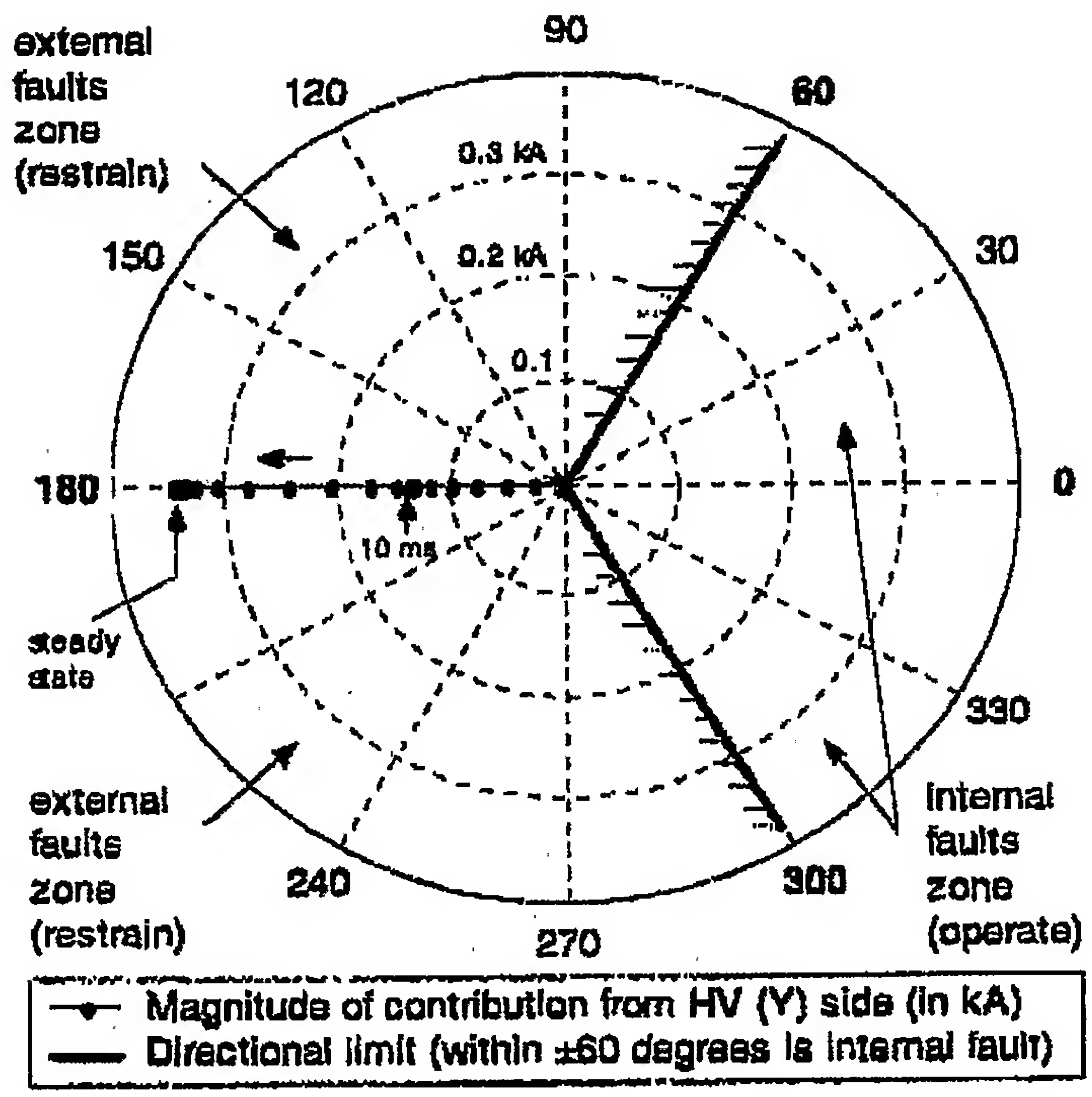
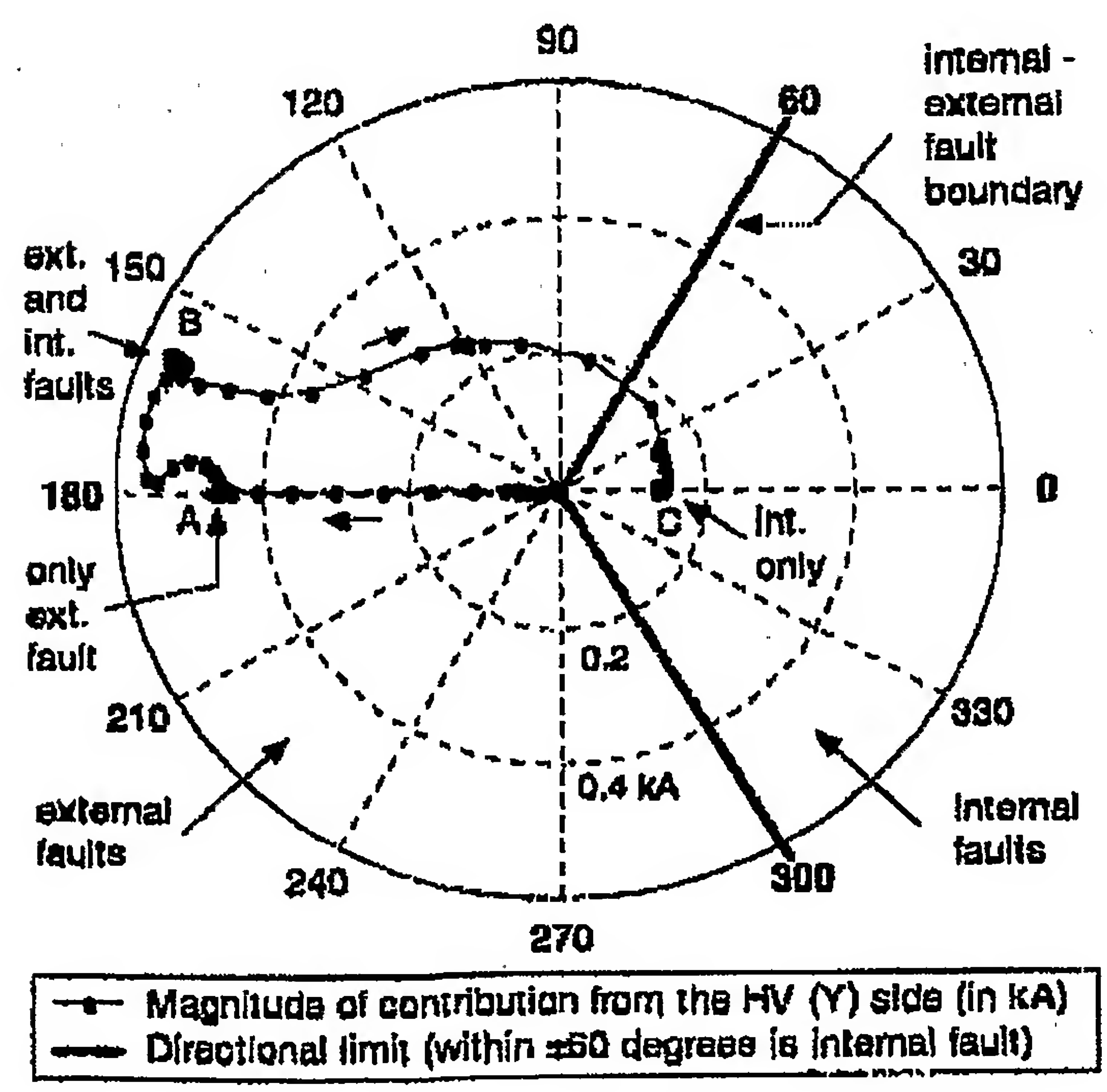

external faults zone (restrain)
90
120
60
0.3 kA
0.2 kA
0.1
150
30
180
0
10 ms
steady state
330
external faults zone (restrain)
240
300
270
internal faults zone (operate)
Magnitude of contribution from HV (Y) side (in kA)
Directional limit (within ±60 degrees is internal fault)

Figure 3


90
120
60
internal - external fault boundary
ext. and int. faults
150
B
30
180
A
C
int. only
0
only ext. fault
0.2
210
330
external faults
0.4 kA
internal faults
240
300
270
Magnitude of contribution from the HV (Y) side (in kA)
Directional limit (within ±60 degrees is internal fault)

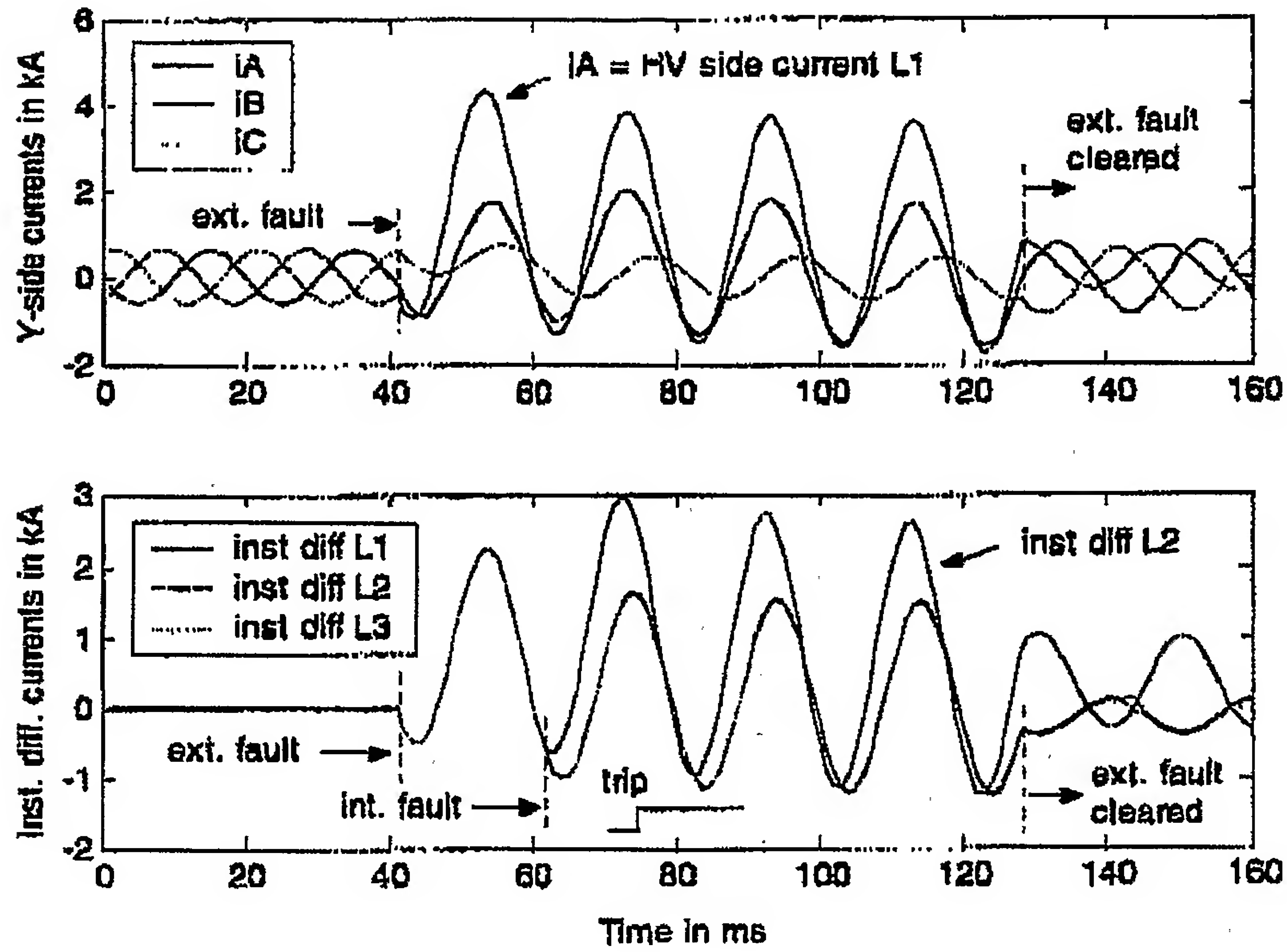
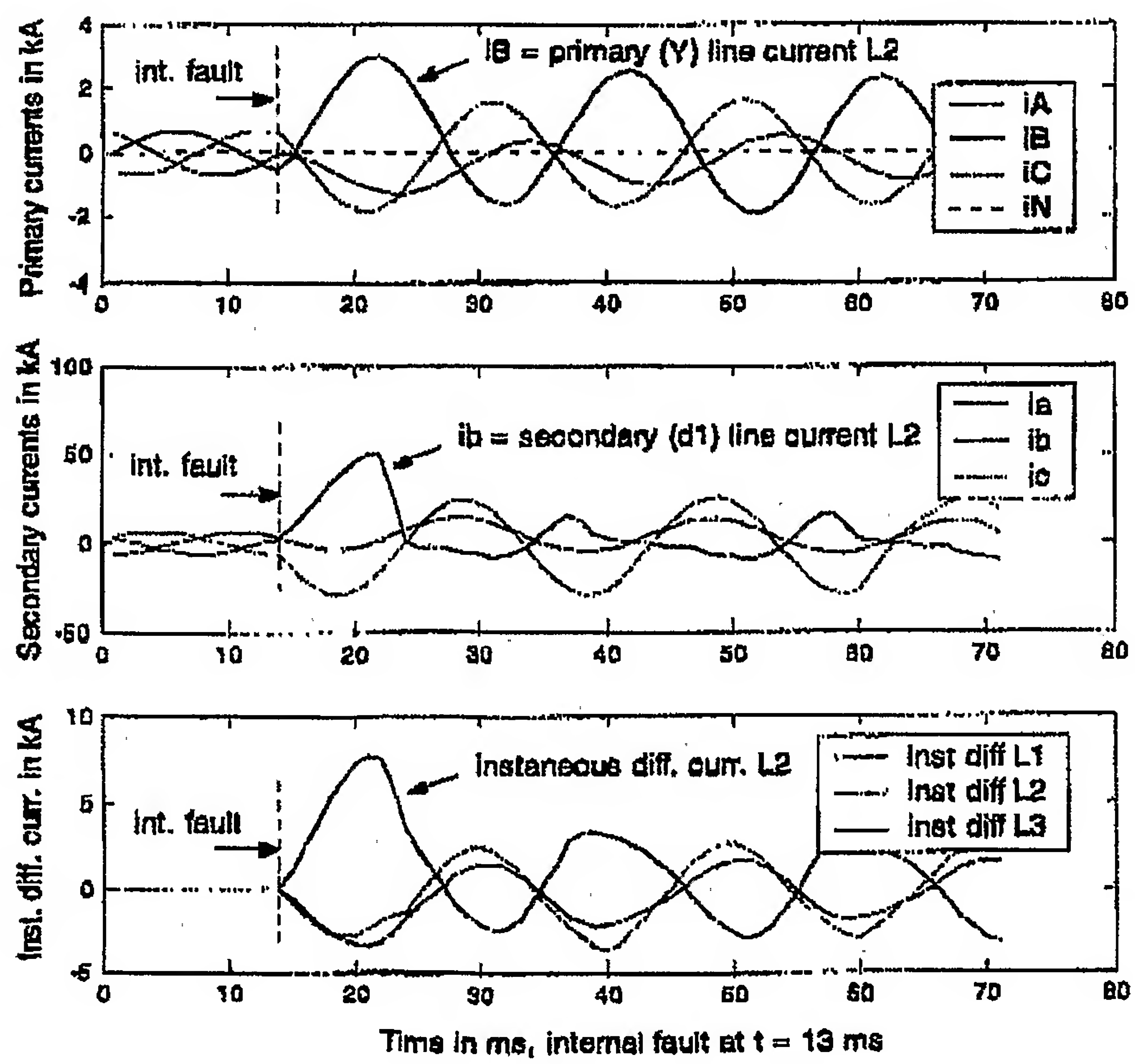

iA
iB
iC
IA = HV side current L1
ext. fault
ext. fault cleared
Y-side currents in kA
inst diff L1
inst diff L2
inst diff L3
inst diff L2
ext. fault
int. fault
trip
ext. fault cleared
Inst. diff. currents in kA
Time in ms

Figure 5


int. fault
IB = primary (Y) line current L2
iA
iB
iC
iN
Primary currents in kA
int. fault
ib = secondary (d1) line current L2
ia
ib
ic
Secondary currents in kA
Instaneous diff. curr. L2
int. fault
Inst diff L1
Inst diff L2
Inst diff L3
Inst. diff. curr. in kA
Time in ms, internal fault at t = 13 ms

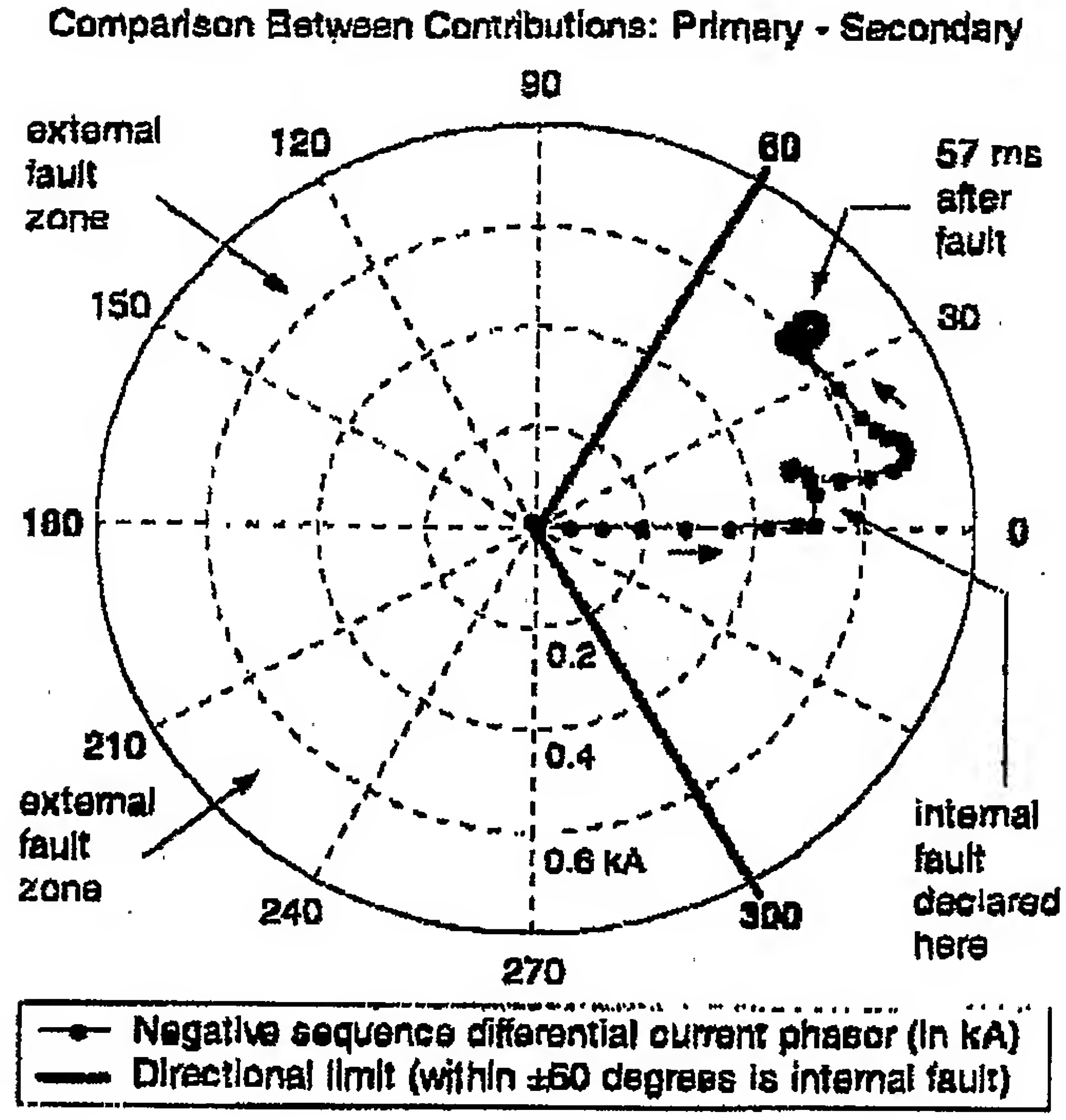


Figure 7

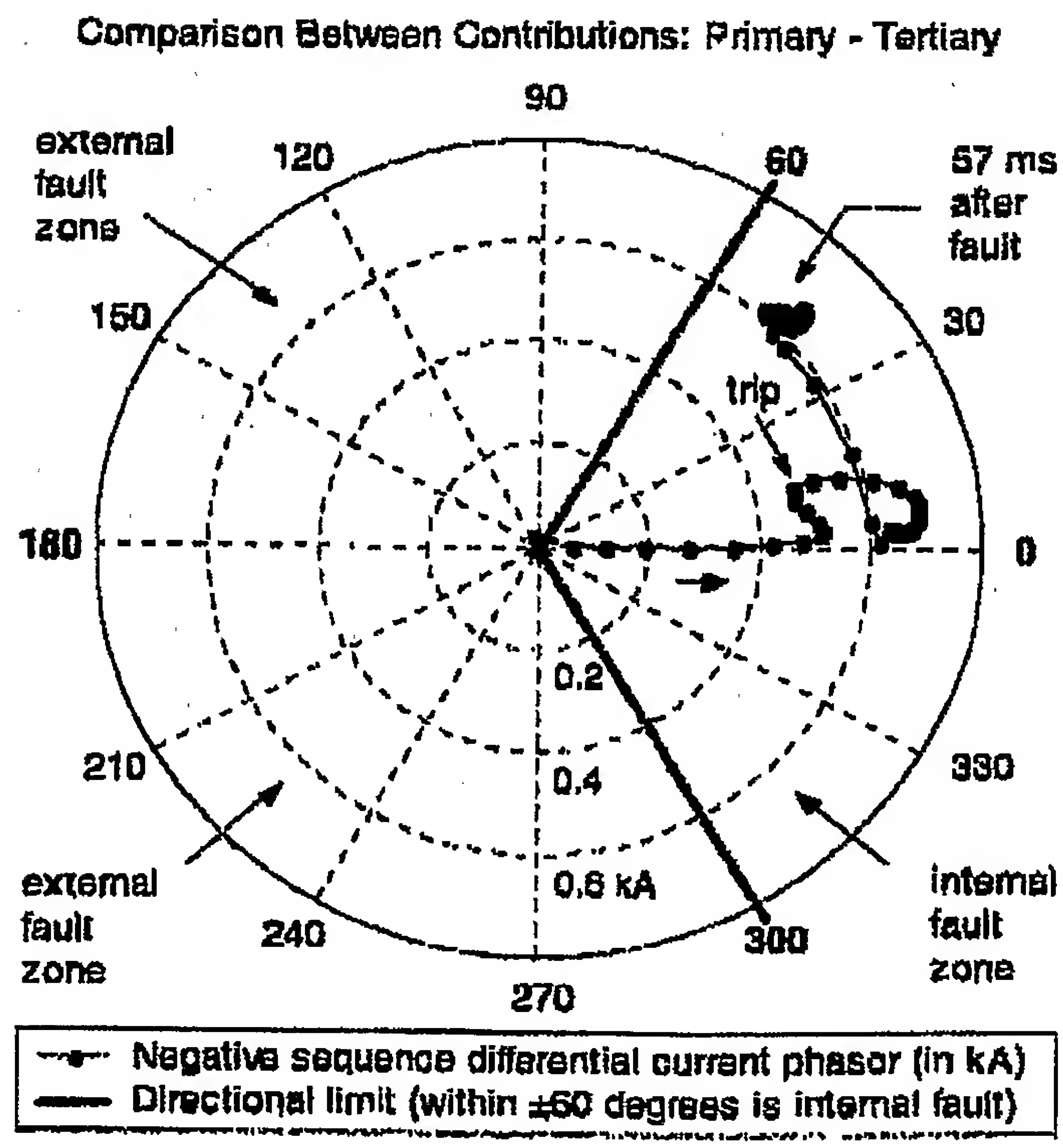


Figure 8

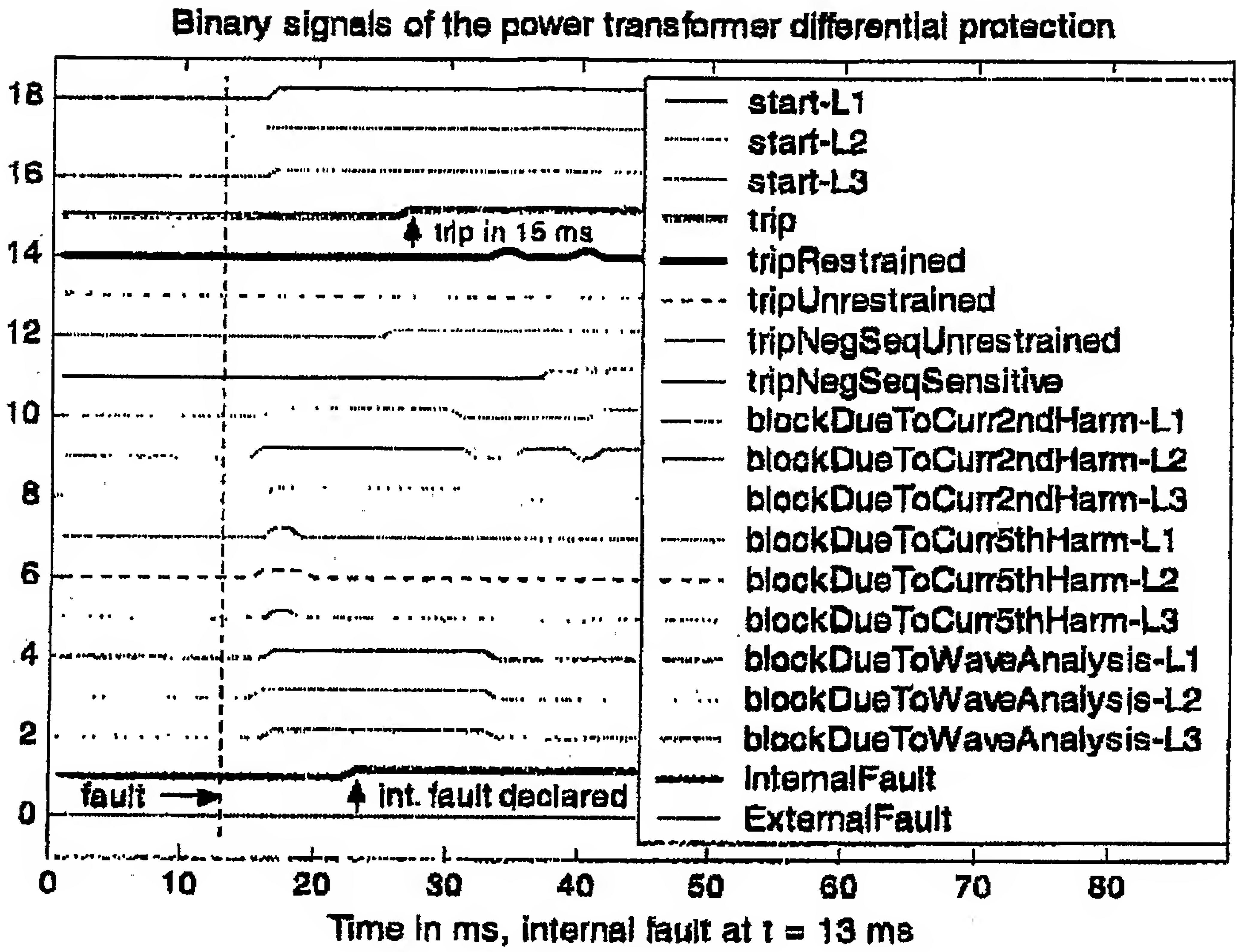
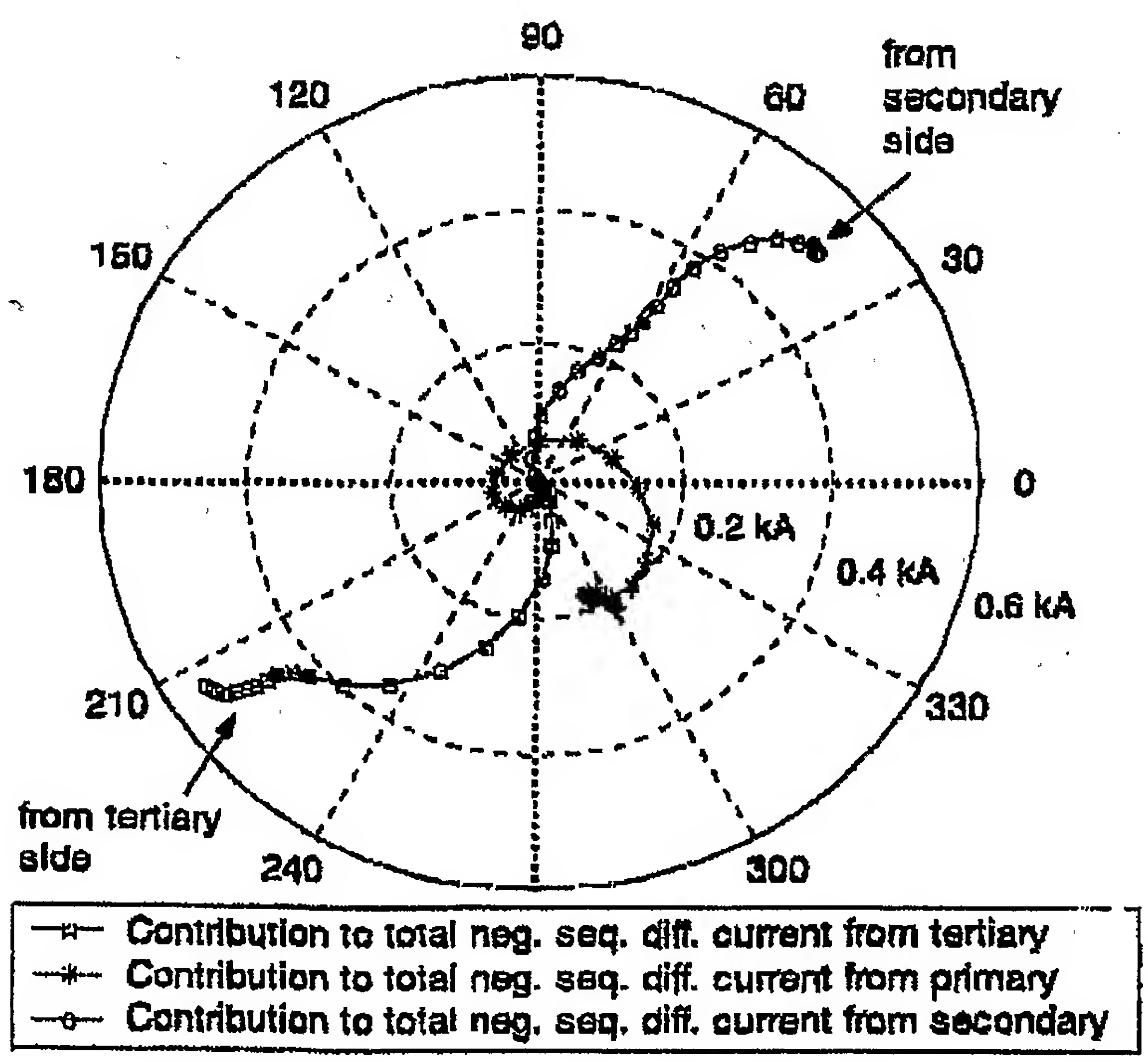
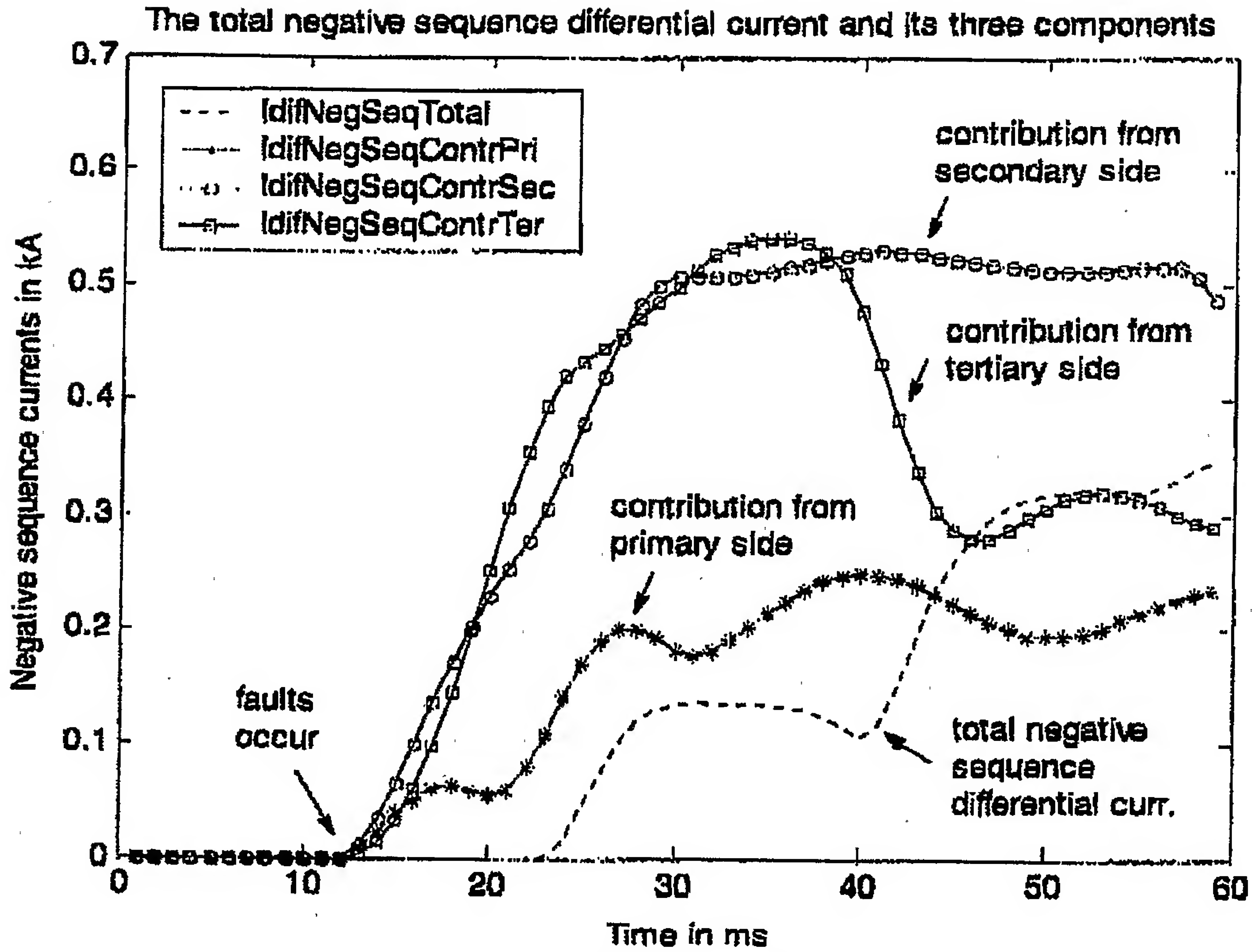

Binary signals of the power transformer differential protection
18
16
14
12
10
8
6
4
2
0
trip in 15 ms
fault
int. fault declared
start-L1
start-L2
start-L3
trip
tripRestrained
tripUnrestrained
tripNegSeqUnrestrained
tripNegSeqSensitive
blockDueToCurr2ndHarm-L1
blockDueToCurr2ndHarm-L2
blockDueToCurr2ndHarm-L3
blockDueToCurr5thHarm-L1
blockDueToCurr5thHarm-L2
blockDueToCurr5thHarm-L3
blockDueToWaveAnalysis-L1
blockDueToWaveAnalysis-L2
blockDueToWaveAnalysis-L3
InternalFault
ExternalFault
0 10 20 30 40 50 60 70 80
Time in ms, internal fault at t = 13 ms

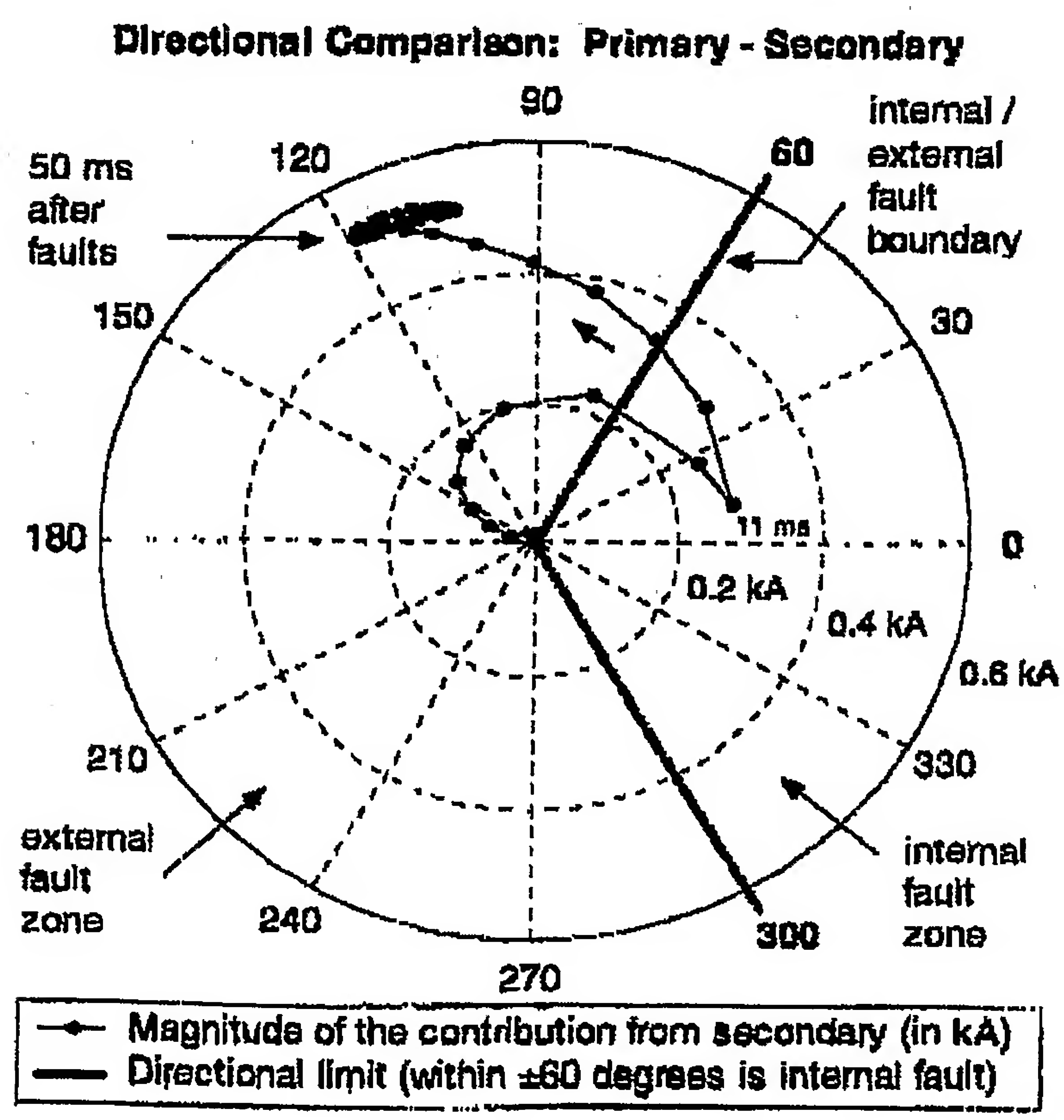
Figure 9


90
120
60
from secondary side
150
30
180
0
0.2 kA
0.4 kA
0.6 kA
210
330
from tertiary side
240
300
Contribution to total neg. seq. diff. current from tertiary
Contribution to total neg. seq. diff. current from primary
Contribution to total neg. seq. diff. current from secondary



The total negative sequence differential current and its three components
IdifNegSeqTotal
IdifNegSeqContrPri
IdifNegSeqContrSec
IdifNegSeqContrTer
contribution from secondary side
contribution from tertiary side
contribution from primary side
faults occur
total negative sequence differential curr.
Negative sequence currents in kA
Time in ms
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10
20
30
40
50
60

Figure 11



Directional Comparison: Primary - Secondary
90
120
60
150
30
180
0
210
330
240
300
270
50 ms after faults
internal / external fault boundary
11 ms
0.2 kA
0.4 kA
0.6 kA
external fault zone
internal fault zone
Magnitude of the contribution from secondary (in kA)
Directional limit (within ±60 degrees is internal fault)

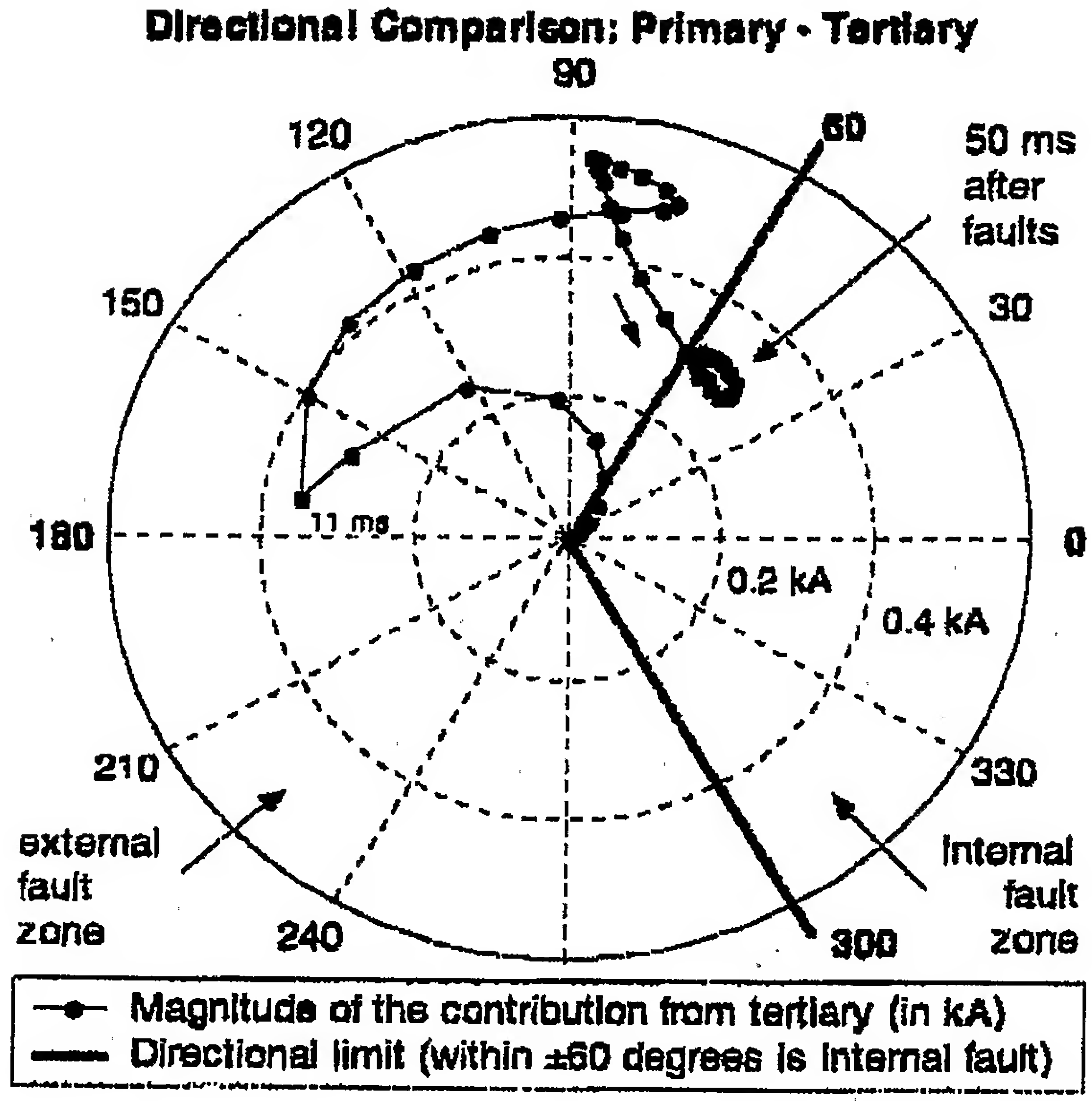


Figure 13

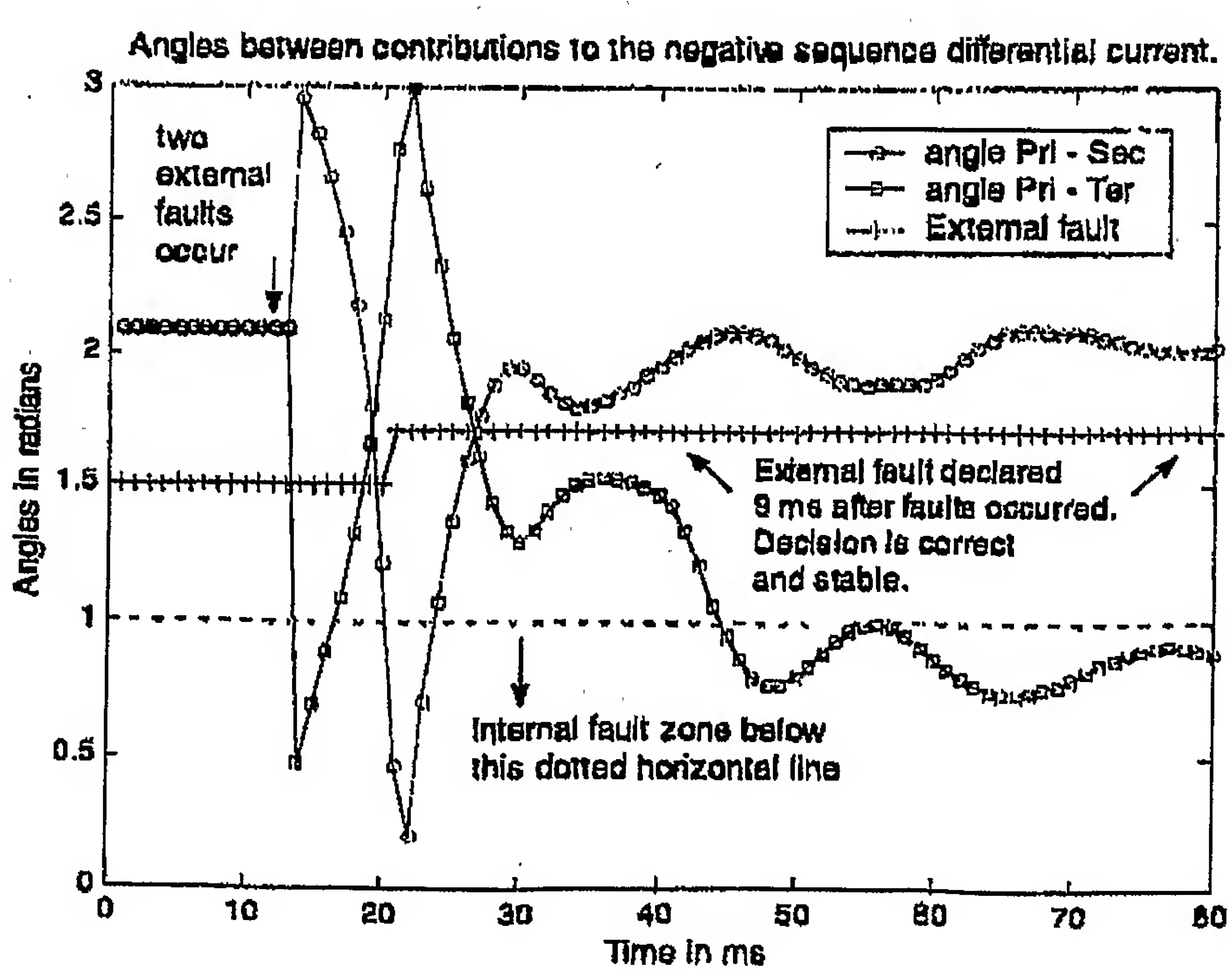


Figure 14

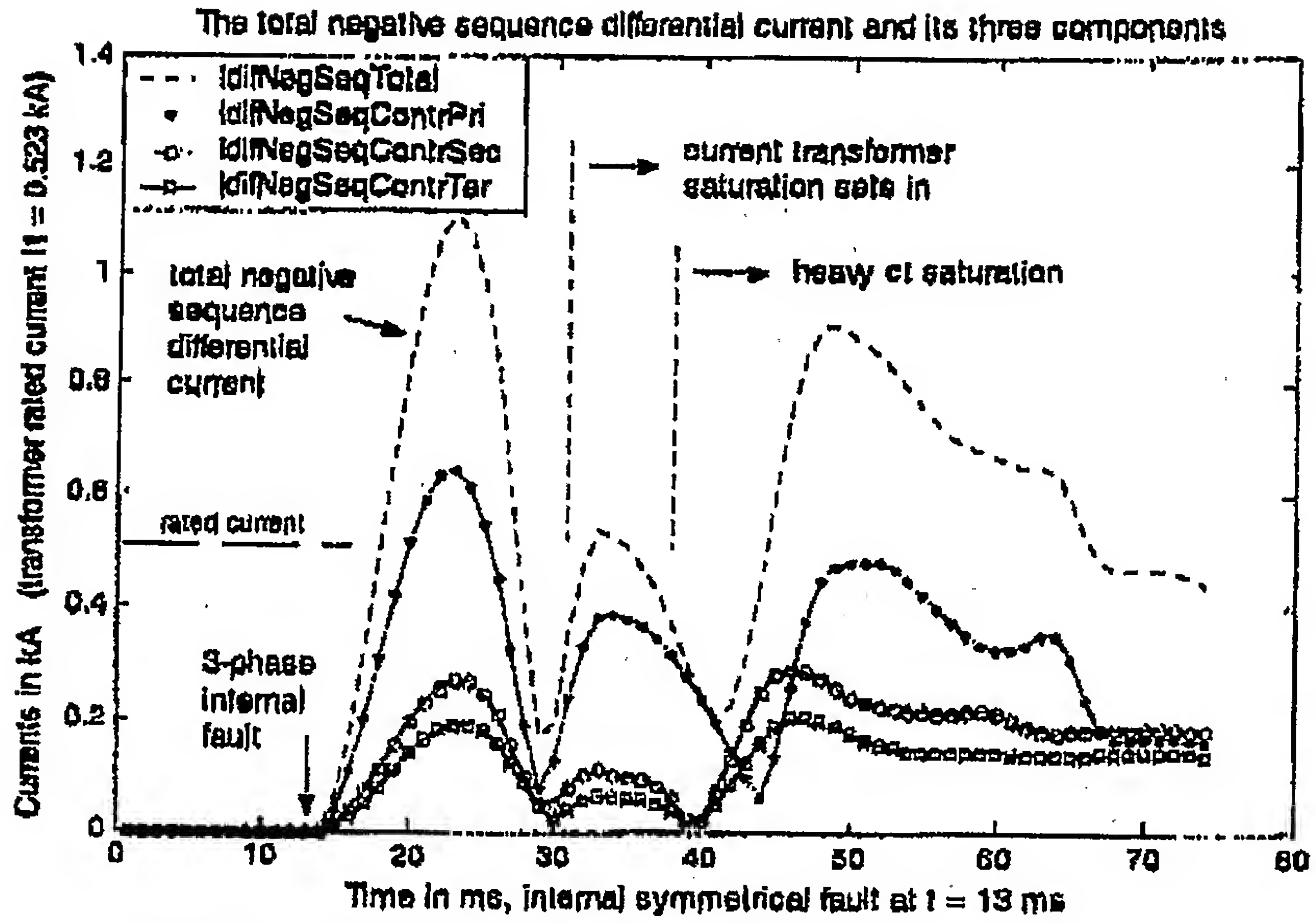


Figure 15

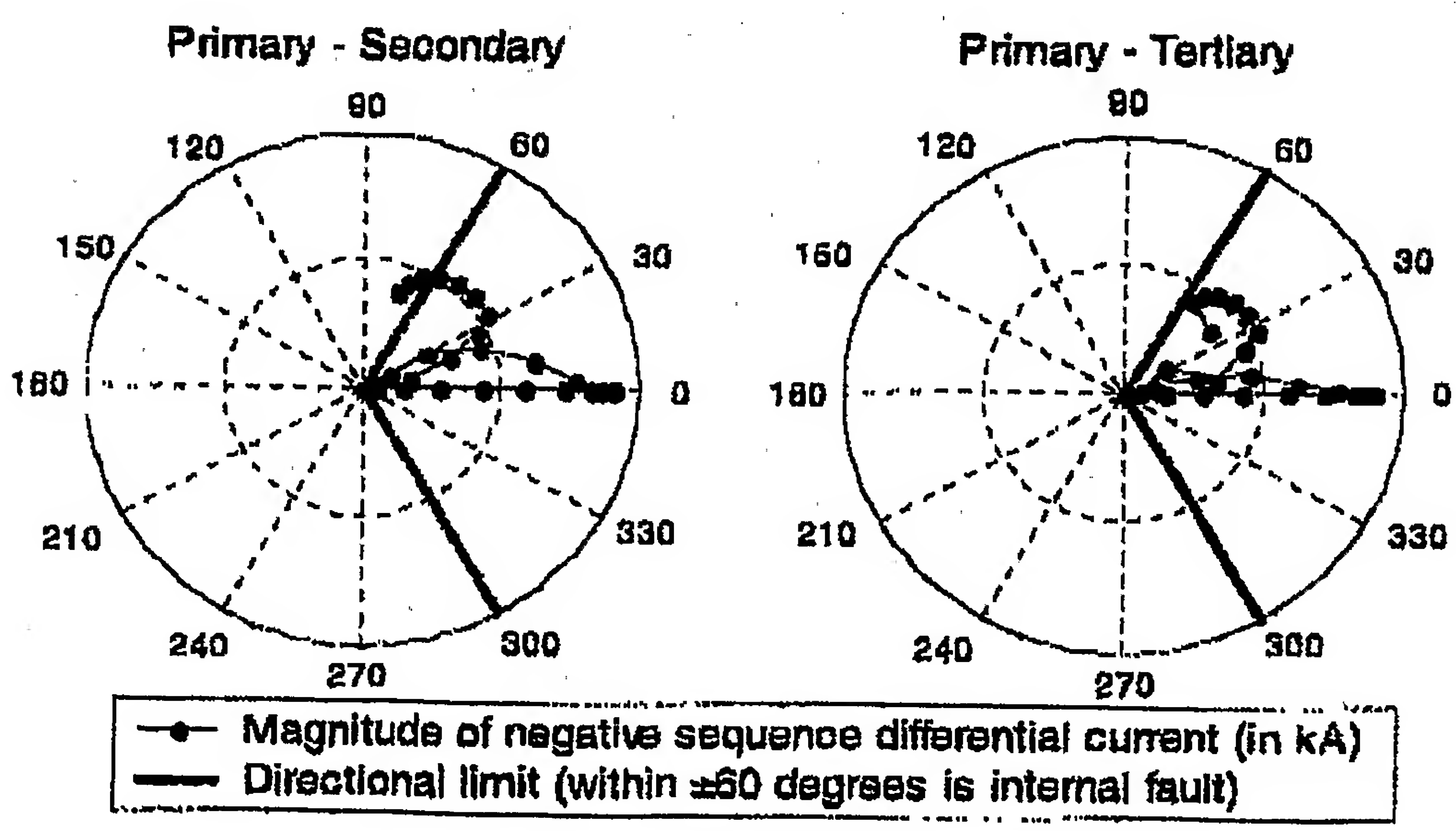
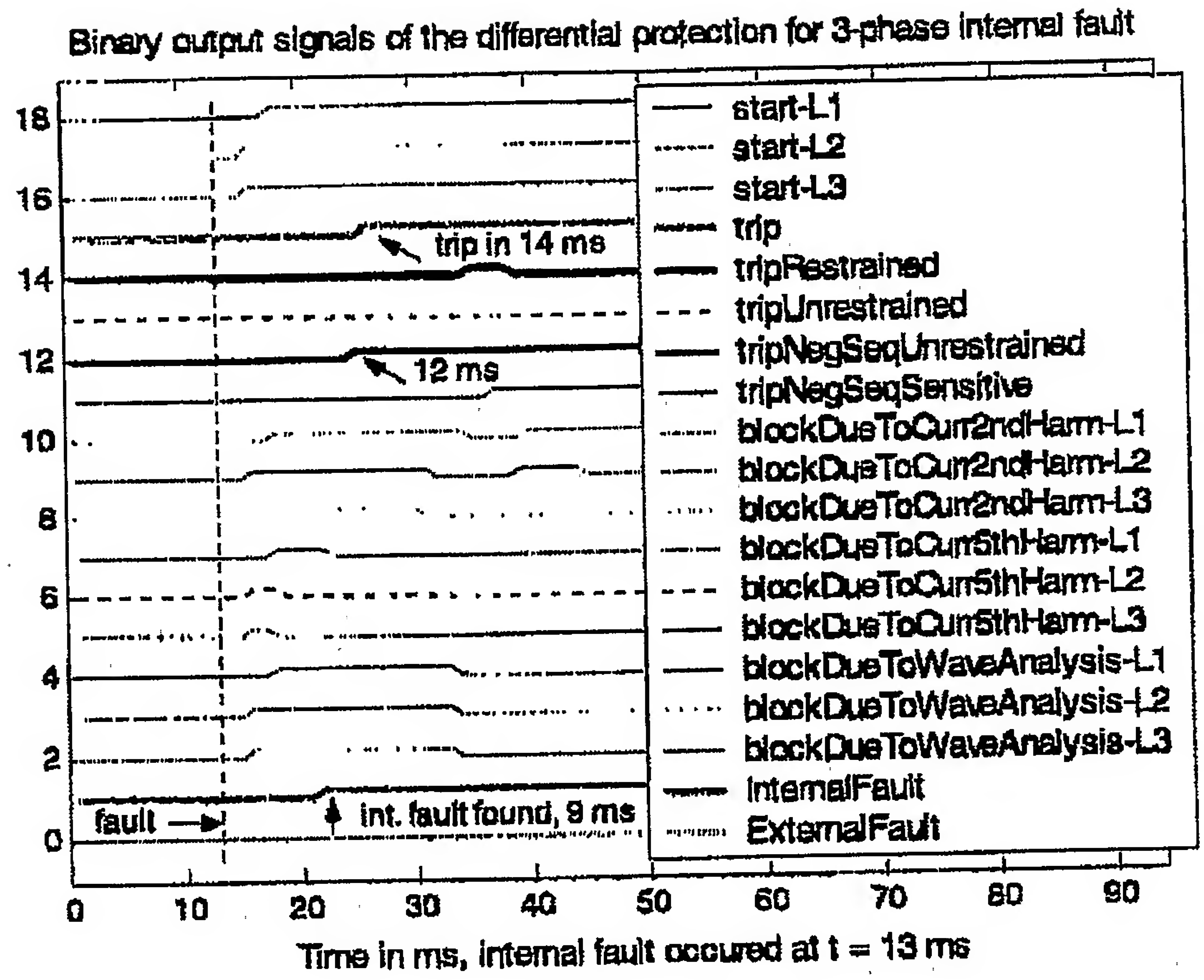


Figure 16



Binary output signals of the differential protection for 3-phase internal fault
18
16
14
12
10
8
6
4
2
0
trip in 14 ms
12 ms
fault
int. fault found, 9 ms
start-L1
start-L2
start-L3
trip
tripRestrained
tripUnrestrained
tripNegSeqUnrestrained
tripNegSeqSensitive
blockDueToCurr2ndHarm-L1
blockDueToCurr2ndHarm-L2
blockDueToCurr2ndHarm-L3
blockDueToCurr5thHarm-L1
blockDueToCurr5thHarm-L2
blockDueToCurr5thHarm-L3
blockDueToWaveAnalysis-L1
blockDueToWaveAnalysis-L2
blockDueToWaveAnalysis-L3
InternalFault
ExternalFault
0
10
20
30
40
50
60
70
80
90
Time in ms, internal fault occured at t = 13 ms

Figure 17